Evolutionary Programming and Iteration Particle Swarm Optimization for Optimal Spinning Reserve of a Wind-Thermal Power System

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Article Info
Article history:
Received 4 February 2015
Received in revised form
20 February 2015
Accepted 28 February 2015
Available online 6 March 2015

Keywords
OSWRT Power System,
Evolutionary Iteration Particle Swarm Optimization,
Up Spinning Reserve,
Down Spinning Reserve

Abstract
This paper discusses the Evolutionary programming and Iteration particle swarm optimization for OSRWT problem. Evolutionary iteration particle swarm optimization algorithm which is the combination of evolutionary programming (EP) and improved particle swarm optimization (IPSO). Those combined algorithms used to solving the nonlinear optimal scheduling problem. The optimal spinning reserve of a wind-thermal power system (OSRWT) using EIPSO method to evaluate the selection of spinning reserve. For evaluate the level of spinning reserve, the thermal unit consider total operation cost and outage cost in the OSRWT problem. By minimizing the total social cost the optimal spinning reserve was reached easily. The OSRWT problems introduce the up spinning reserve (USR) and down spinning reserve (DSR). The EIPSO algorithm is implemented using crossover, selection and Mutation procedure.

1. Introduction

The most important economic benefits of wind power reduce the exposure of our economies to fuel cost. Due to the low environmental impact, market scalability decreasing capital cost, the wind energy is continuously increased. The wind turbine generator (WTGs) directly connected to the utility system, which is important to study the impact of WTG in the power system [1]. In the generation scheduling problem two level of spinning reserve has considered in the wind turbine generator (WTGs). There are two level of spinning reserve used in this paper that is up spinning reserve (USR), down spinning reserve (DSR). The USR is nearly related to, and proportional the WGSs power output. As increases output of WGS there is more generation unit should be turned on to supply the incremental USR necessity distributed by wind generating system. This increased WGSs output reduces the fuel price of the power system [2]. The unfortunate decreases in load and unpredictable increases in WTG power output is known as DSR. When only the down spinning reserve is not included in the power system operation, the thermal generation unit should be turned on and off often. Some of the generation unit should be turned onto give extra supply to the down spinning reserve which is given by the WGS. The USR and DSR is coordinated when the operation of WTGs. This however increases the system reliability of the power system. The stochastic criteria do not match for the determination of the spinning reserve level. The use of deterministic method to keep the level of spinning reserve will be larger than the fraction of the system load [3].

The outage cost and operating cost also consisting in the OSRWT solution procedure. In the wind-thermal power system that minimizes the sum of outage cost and operating cost by using the operating constraint, which is the objective function of optimal spinning reserve of a wind-thermal problem (OSRWT). By using the deterministic criteria method the spinning reserve level has been found, and reliability of the power system operation. This is including both of the WTGs and thermal unit. By using the deterministic method or thumb rules method, the electric power industry determining the operating reserve requirement. This method does not match for many factors which is the disadvantage in the deterministic method. There is the considerable reluctance apply to the probabilistic technique to overcome the disadvantage of this method.

Reducing operating cost and increasing system reliability is delivered by the study of spinning reserve scheduling problem. There are many approaches in the spinning reserve scheduling problem, those approaches are Monte carlo simulation, Linear programming method [4], Lagrange relaxation [6] and decomposition techniques [5]. The study of WTGs and probability reserve is very few in the OSRWT problem. Genetic algorithm (GA), simulated annealing method (SA) [7], Evolutionary programming (EP), these are the stochastic search algorithm. This algorithm gives reasonable solution but do not always guarantee which are the demerits in this stochastic method.

Kennedy and Eberhart presented the particle swarm optimization approach (PSO). Its based on the social behaviour of bird flocking and fish schooling, within the shorter computation time the PSO gives high solution quality [8]. The stochastic method does not give more stable convergence compared to this deterministic method. Solving method of the OSRWT problem in this paper is called evolutionary iteration particle swarm optimization (EIPSO). EIPSO can evaluate the effects in the on-line and off-line applications.

2. Problem Formulation

2.1 Objective Function

The objective function of the paper is minimizing the total social cost [3]. The objective function of the OSRWT is given as below:

$$\text{Minimize TSC}=\sum_{t=1}^{T} TOC_t + \omega 1 \times OC_t \qquad (1)$$

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$$OC_t = EENS_t \times VOLL \quad (2)$$

$$TOC_t = \sum_{n=1}^{N}[FC_{n,t} + SC_{n,t}] \quad (3)$$

$$FC_{n,t} = A_n + B_n \times P_{n,t} + C_n \times P_{n,t}^2 \quad (4)$$

$$SC_{n,t} = d0(1 - e^{\frac{T_{n,t}^{off}}{d1}}) + d2 \quad (5)$$

For long term planning studies the EENS concept formulated originally. The EENS expressed below:

$$EENS_t = \sum_{h=1}^{H} IP(X_h) \times EC_h \quad (6)$$

$$IP(X_h) = P(X_h) - P(X_{h+1}) \quad (7)$$

$$EC_h = \begin{cases} LD_t - (SP_t - X_h), When LD_t \geq SP_t - X_h \\ 0, otherwise \end{cases} \quad (8)$$

$$SP_t = \sum_{n=1}^{N} P_{n,t}^{\max} + \sum_{y=1}^{NW} WT_{y,t} \quad (9)$$

2.2 Constraint

2.2.1 Real Power Balance

Equality constraint reflects the real power balance, the real power balance constraint expressed below:

$$\sum_{n=1}^{N} P_{n,t} + WT_t = LD_t \quad (10)$$

2.2.2 Real power operating limit of generation unit

Inequality constraints reflect the real power operating limits. Inequality constraint given as:

$$P_{n,t}^{\min} \leq P_{n,t} \leq P_{n,t}^{\max}, n \in N \quad (11)$$

$$0 \leq W_{y,t} \leq W_y^{\max}, y \in NW \quad (12)$$

2.2.3 Spinning reserve constraint

Spinning reserve is nothing but an unscheduled generator outage.

$$USR_t = \sum_{n=1}^{N} UR_{n,t} \geq LSR_t + WT_t \times \omega u\% \quad (13)$$

$$UR_{n,t} = Min(P_n^{\max} - P_{n,t}, T10 \times RU_n) \quad (14)$$

$$LSR_t = Max(P_{n,t}), n \in N \quad (15)$$

$$DSR_t = \sum_{n=1}^{N} DR_{n,t} \geq (\sum_{y=1}^{NW} W_y^{\max} - WT_t) \times \omega d\% \quad (16)$$

$$DR_{n,t} = Min(P_{n,t} - P_{n,t}^{\min}, T60 \times RD_n) \quad (17)$$

2.2.4 Minimum up time and down time of generation units

$$T_{n,t-1}^{on} \geq Tu_n, When T_{n,t}^{off} = 1 \quad (18)$$

$$T_{n,t-1}^{off} \geq Td_n, When T_{n,t}^{on} = 1 \quad (19)$$

2.2.5 Generation limit of thermal generation system

$$\sum_{n=1}^{N} P_{n,t}^{\max} + WT_t \geq LD_t + LSR_t + WT_t \times \omega u\% \quad (20)$$

$$P_{n,t}^{\max} = Min(P_n^{\max}, P_{n,t-1} + RU_n \times T60) \quad (21)$$

$$LD_t - WT_t \geq \sum_{n=1}^{N} P_{n,t}^{\min} - (\sum_{y=1}^{NW} W_y^{\max} - WT_t) \times \omega d\% \quad (22)$$

$$P_{n,t}^{\min} = Max(P_n^{\min}, P_{n,t-1} - RD_n \times T60 \quad (23)$$

2.2.6 Generation limit of wind generation system

$$WT_t - WT_{t-1} \leq \sum_{n=1}^{N}[Min(RD_n \times T60, P_{n,t-1} - P_n^{\min})], When WT_t \geq WT_{t-1} \quad (24)$$

$$WT_{t-1} - WT_t \leq \sum_{n=1}^{N}[Min(RU_n \times T60, P_n^{\max} - P_{n,t-1})], When WT_t \leq WT_{t-1} \quad (25)$$

2.2.7 Ramping speed of thermal generation unit

$$P_{n,t}^{\min} \leq P_{n,t} \leq P_{n,t}^{\max} \quad (26)$$

3. EP Algorithm

Step 1: Get the demand for 24 hours and no. of iterations to be carried out.
Step 2: Generate population of parents (N) by adjusting the existing solution to the given demand to the form of state variables.
Step 3: Unit down time makes a random recommitment.
Step 4: Check for constraint in the new schedule. If the constraints are not met then repair the schedule as given in the repair mechanism section.
Step 5: Perform ELD and calculate total production cost for each parent.
Step 6: Add the Gaussian random variable to each state variable and hence create an offspring. This will further undergo for some repair operations as given in the making offspring feasible section. Following these, the new schedules are checked in order to verify that all constraints are met.
Step 7: Improve the status of the evolved offspring
Step 8: Formulate the rank for the entire population.
Step 9: Select the best N number of population for next iteration.
Step 10: Has iteration count reached? If yes go to step 11 else go to step 2.
Step 11: Select the best population (s) by Evolutionary strategy.
Step 12: Print the optimum schedule.

4. Implementation of EIPSO

For computational efficiency improved particle swarm optimization (IPSO) combines with the evolutionary programming (EP), this is known as EIPSO.

The OSRWT problem solved using the EIPSO algorithm. Solution method and step by step procedure of the evolutionary iteration particle swarm optimization (EIPSO) algorithm is given below:

Step 1 Calculation of the wind power generation.

$$W_{y,t} = \begin{cases} W_y^{\max}, U_t \geq UF \\ a.U_t^3 + b.U_t^2 + c.U_t, UD \leq U_t \leq UF \\ 0, U_t \leq UD \end{cases} \quad (27)$$

equation (27) is used to calculate the wind turbine generator power output. The long term wind speed data recorded at the test site for calculate the hourly wind speed data's.

Step 2 Parameters in EIPSO

i. population size J.
ii. Weighted factor c1=30; c2=44; c3=c.$(1 - e^{c1.k})$
iii. Mutation scaling factor β.
iv. No of competitors M.
v. Max no of iteration IT_{max}

Based on the experimental result the those parameters have selected.

Step 3 Initial population created randomly.

$$P_{N,t} = LD_t - WT_t - \sum_{n=1}^{N} P_{n,t}, t = 1,2,3,...T \quad (28)$$

The initial population created by X_j^K, j=1,2,3...J. The element of Nth row, that is $P_{n,t}$ determined by equation (28).

Step 4

Adjust each individual by the wind generation

For unpredictable wind speed the power system could not adjust speed of wind. By adjusting the turbine blades the wind generation can be achieved.

a) If $WT_t - WT_{t-1} \leq \sum_{n=1}^{N}[Min(RD_n \times T60, P_{n,t-1} - P_n^{\min})], When WT_t \geq WT_{t-1}$ is conflicted, set WT_t as the sum of WT_{t-1} and the right hand side term of the above equation. Recalculate $P_{N,t}$ by (28).

b) If $WT_{t-1} - WT_t \leq \sum_{n=1}^{N}[Min(RU_n \times T60, P_n^{\max} - P_{n,t-1})], When WT_t \leq WT_{t-1}$ is conflicted, set WT_{t-1} as the sum of WT_t and the right hand side term of the above equation. Recalculate $P_{N,t-1}$ the by replacing t with t-1 in (28).

c) If $\sum_{n=1}^{N} P_{n,t}^{\max} + WT_t \geq LD_t + LSR_t + WT_t \times \omega u\%$ is conflicted, subtract $\sum_{n=1}^{N} P_{n,t}^{\max}$ from the right hand side term of above equation, and set the result as WT_t. Recalculate $P_{N,t}$ by (28).

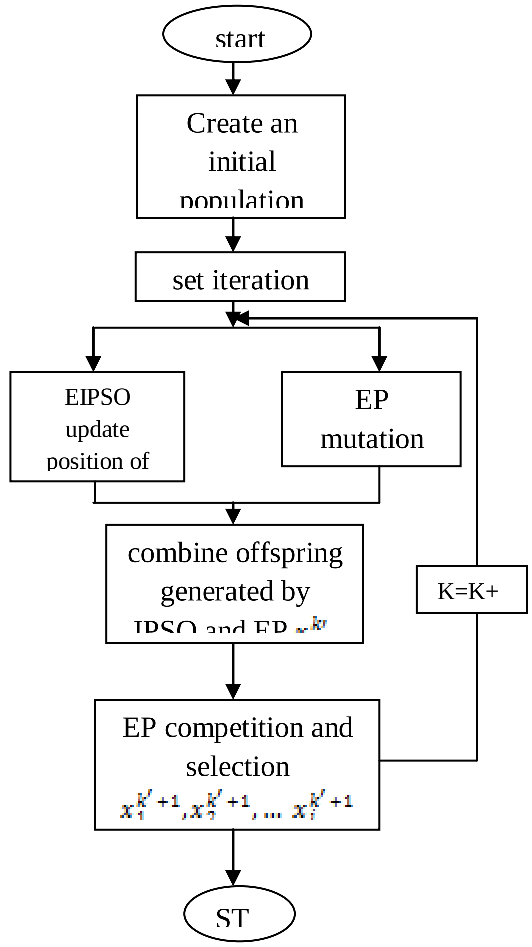

Fig: 1. Flow chart for EIPSO

d) If $LD_t - WT_t \geq \sum_{n=1}^{N} P_{n,t}^{\min} - (\sum_{y=1}^{NW} W_y^{\max} - WT_t) \times \omega d\%$ is conflicted, subtract the right hand side term of the above equation from LD_t, and set the result as WT_t. Recalculate $P_{N,t}$ by (28).

Step 5 Evaluate the fitness of individual.

$$FT(X_j^K) = TSC + \sum_{E=1}^{6}(\gamma E \sum_{t=1}^{T} CS_{j,E,t}^K) \quad (29)$$

$$CS_{j,1,t}^K = \left| \sum_{n=1}^{N} P_{n,t}^K - LD_t - WT_t \right| \quad (30)$$

$$CS_{j,2,t}^K = \sum_{n=1}^{N} \left| P_{n,t}^K - PN_n \right| \quad (31)$$

$$PN_n = \begin{cases} P_{n,t}^{\max}, When P_{n,t}^{K} > P_{n,t}^{\max} \\ P_{n,t}^{\min}, When P_{n,t}^{K} < P_{n,t}^{\min} \\ P_{n,t}^{K}, Otherwise \end{cases} \quad (32)$$

$$CS_{j,3,t}^{K} = \psi(LSR_t + WT_t + \times \omega u\% - \sum_{n=1}^{N} UR_{n,t}) \quad (33)$$

$$\psi(q) = \begin{cases} q, q \ge 0 \\ 0, q < 0 \end{cases} \quad (34)$$

$$CS_{j,4,t}^{K} = \psi[(\sum_{y=1}^{NW} W_y^{\max} - WT_t) \times \omega d\% - \sum_{n=1}^{N} DR_{n,t}] \quad (35)$$

$$CS_{j,5,t}^{K} = \sum_{n=1}^{N} RC_{n,t}^{K} \quad (36)$$

$$RC_{n,t}^{K} = \psi(P_{n,t}^{\min} - P_{n,t}) + \psi(P_{n,t} - P_{n,t}^{\max}) \quad (37)$$

$$CS_{j,6,t}^{K} = \sum_{n=1}^{N} TT_{n,t}^{K} \quad (38)$$

$$TT_{n,t}^{K} = \begin{cases} \psi(Tu_n - T_{n,t-1}^{on}), When T_{n,t}^{off} = 1 \\ \psi(Td_n - T_{n,t-1}^{off}), When T_{n,t}^{on} = 1 \\ 0, Otherwise \end{cases} \quad (39)$$

The above equation gives the fitness function of OSRWT problem.

Step 6

Update velocity and position of particle.

There are two methods are used to generate the offspring from X_j^K, j=1,2,3..J.The first method uses IPSO to update the particle position, and other uses EP mutation.

This step updates the positions of X_j^K, j=1,2,3..J to be $X_j^{K'}$, j=1,2,3..J represented in figure, to be part of the offspring of the next generation.

$$V_j^{k+1} = V_j^k + c1.rand.(Pbest_j^k - X_j^k) + c2.rand.(Gbest^k - X_j^k) + c3.rand.(Ibest^k - X_j^k) \quad (40)$$

Equation (40) is applied to update the velocity of particle. The velocity of particle is represented as a N$\times D$ dimension matrix that represents a movement of the generation of thermal units.

$$X_j^{k+1} = X_j^k + V_j^{k+1} \quad (41)$$

Equation (41) is applied to update the position of particle is the generation of thermal units. This step also update Pbest,Gbest and Ibest.

Step7

EP Mutation

This step generate the offspring by the below equation

$$X_{j+J}^{k'} = X_j^k + \sigma_j N_j(0,1) \quad (42)$$

$$X_{j+J}^{k'} = X_j^k + \sigma_j C_j(0,1) \quad (43)$$

The better one of (42) and (43) becomes the offspring of the next generation, which are represented as $X_j^{K'}$, j=1,2,3..J

Step 8

Competition and selection based on EP.

$$S_j = \sum_{r=1}^{M} S_r \quad (44)$$

$$S_r = \begin{cases} 1, if u 1 < \dfrac{f_i}{f_i + f_j} \\ 0, Otherwise \end{cases} \quad (45)$$

These equation compute the competition scores of all individuals obtain their competition scores, They will ranked in descending order of their corresponding competition scores. The first 'J' individuals from the next generation,

X_j^{K+1}, j=1, 2, 3..J

Step 9

END condition

The end condition of EIPSO are as follows:

1) The total social cost between two consecutive iterations is unchanged or the variation of total social cost is within a permit range for 5 iterations.

2) The maximum number of iteration is reached.

Step 10

Up spinning reserve and down spinning reserve is calculated by using the equations (13),(14) and (16),(17).

4. Result

In this paper, the Lagrangian Relaxation method is used to solve unit commitment problem with and without considering wind power. In order to validate the efficiency of the proposed methodology for performing unit commitment an IEEE test system consisting of 6 generating unit. Initially the LR approach is developed using MATLAB 2010Ra software. The power generation of wind is calculated for 24 hours. The data for individual units and the ramp rate limits are given below table. The comparison of the PSO and EIPSO numerical output is validated for the OSRWT.

Table: 1: Generating Coefficient

S. no	a_i (\$/MWh^2)	b_i (\$/MWh)	c_i (\$/h)	P^{max} (MW)	P^{min} (MW)
1	0.0070	7.0	240	500	100
2	0.0095	10.0	200	200	50
3	0.0090	8.5	220	300	80
4	0.0090	11.0	200	150	50
5	0.0080	10.5	220	200	50
6	0.0075	12.0	190	120	50

Table: 2. Ramp Rate Limits

Unit	P_i^0	UR_i	DR_i
1	440	80	120
2	170	50	90
3	200	65	100
4	150	50	90
5	190	50	90
6	110	50	90

Finally the objective function of OSRWT problem Total social cost is found in table VI. The optimal spinning reserve of a wind-thermal power system has been computed for 24 hours per a day.

Then using EIPSO algorithm the optimal spinning reserve of a wind-thermal power system gives shorter computation time compared to other technical methods. The comparison of the PSO and EIPSO output of the OSRWT problem is given in the below table V.

Table: 3. Comparison of PSO and EIPSO Algorithm

Algorithm	Average of total social cost ($)	Average computation time (sec)
EP	1,189,874	1,457
PSO	1,176,567	1,345
EIPSO	1,145,453	734

5. Conclusion

This paper show the EIPSO efficient output for OSRWT problem, which is determined the spinning reserve requirement that also overcome the unscheduled generator outage. EIPSO with OSRWT problem evaluated with and without wind power system and then which is compared with computational method. The EIPSO solution method give efficient output in the shorter computation time compared with other technical algorithm. EIPSO can applicable in both on-line and off-line application. Finally EIPSO gives efficient output.

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